

APPLICATION  
FOR  
UNITED STATES LETTERS PATENT

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PATENT APPLICATION

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SPECIFICATION

TO ALL WHOM IT MAY CONCERN:

Be it known that Nayef M. Abu-Ageel of 45R Rolling Green Drive, Fall River, MA 02720 has invented certain improvements in SWITCH-VARIABLE OPTICAL ATTENUATOR AND SWITCH ARRAYS, of which the following description is a specification.

PS/CORE73.CVR

## SWITCH-VARIABLE OPTICAL ATTENUATOR AND SWITCH ARRAYS

### Field Of The Invention

This invention relates to optical systems in  
5 general, and more particularly to switches and  
attenuators for use in optical systems.

### Background Of The Invention

In many situations, it is necessary to switch or  
10 attenuate an optical signal that is transmitted within  
an optical system.

By way of example but not limitation, in a typical  
optical system, it may be necessary to switch or  
attenuate an optical signal between a first line (e.g.,  
15 a fiberoptic or fiber line) and a second line (e.g., a  
fiberoptic or fiber line).

Attenuation and switching techniques that exist in  
the art do not address the problem of fast and accurate  
switching and attenuation combined with ease of  
20 implementation.

Summary Of The Invention

One object of the present invention is to provide novel apparatus for switching a light signal in an optical system.

5 Another object of the present invention is to provide novel apparatus for attenuating a light signal in an optical system.

Still another object of the present invention is to provide a novel method for switching a light signal  
10 in an optical system.

Yet another object of the present invention is to provide a novel method for attenuating a light signal in an optical system.

These and other objects of the present invention  
15 are addressed by the provision and use of novel light switches and attenuators. In one form of the invention, a novel 1x2 switch is formed by positioning a movable mirror having a hole therethrough intermediate three fiberoptic lines. In another form  
20 of the invention, an nxn switch is formed by positioning a movable mirror having a plurality of holes therethrough intermediate a plurality of sets of three fiberoptic lines. In still another form of the

invention, a novel light attenuator is formed by positioning a movable arm having a hole therethrough intermediate three fiberoptic elements.

5 Brief Description Of The Drawings

Still other objects and features of the present invention will be more fully disclosed by the following detailed description of the preferred embodiments of the invention, which is to be considered together with  
10 the accompanying drawings, wherein like numbers refer to like parts and further wherein:

Fig. 1 is a schematic drawing showing the operational use of a switch and variable optical attenuator;

15 Fig. 2 is a schematic top view showing a novel 1x2 switch;

Fig. 3 is a top view showing an nxn switch;

Figs. 4a-4d are cross-sectional side views showing the fabrication of the 1x2 switch of Fig. 2;

20 Figs. 5a-5b are cross-sectional side views showing the formation of a hole through the mirror of the 1x2 switch shown in Fig. 2; and

Fig. 6 is a schematic diagram showing a method for making the switch of Fig. 2.

Detailed Description Of The Preferred Embodiments

5 Referring to Fig. 1, there is schematically shown a switch and variable optical attenuator 5 with an input fiber 6, a first output fiber 7 and a second output fiber 8. A transmitter device 6a is attached to input fiber 6. Receiver devices 7a, 8a are attached to  
10 output devices 7, 8, respectively. In a preferred embodiment, switch and variable optical attenuator 5 switches a light beam 9, emitted by transmitter device 6a through input fiber 6, between receiver devices 7a, 8a coupled with first output fiber 7 and second output  
15 fiber 8, respectively. Additionally, switch and variable optical attenuator 5 may switch light beam 9 traveling from receiver devices 7a, 8a to transmitter device 6a. Alternatively, receiver devices 7a, 8a may comprise a single device with two separate receivers.  
20 In another preferred embodiment, switch and variable optical attenuator 5 attenuates light beam 9 as it is switched between first output fiber 7 and second output fiber 8.

Looking now at Fig. 2, there is shown a novel 1x2 switch and variable optical attenuator 5 formed in accordance with the present invention. Switch and variable attenuator 5 utilizes a vertical mirror 10 in conjunction with a first fixed optical fiber 15, a second fixed optical fiber 20, and a third fixed optical fiber 25. Input fiber 6, first output fiber 7 and second output fiber 8 (illustrated in Fig. 1) correspond to first fixed optical fiber 15, second fixed optical fiber 20 and third fixed optical fiber 25 (illustrated in Fig. 2), respectively. Each of the fibers 15, 20 and 25 are contained in v-grooves 166 etched into the structure of switch 5. V-grooves 166 are positioned at known angles relative to one another. For example, this angle may be  $45^\circ$ . As such, the paths of light beams 45, 55, 65, and positioning of mirror 10 relative to these paths, are known.

Still looking at Fig. 2, mirror 10 contains an opening 30. Opening 30 may be a physical opening where the light beams constitute visible light.

Alternatively, opening 30 may comprise a material that acts as a conduit for particular wavelengths of light while mirror 10 comprises another material that acts as

about one end at a point 35. When mirror 10 is in a first end position 40, opening 30 is positioned such that light beam 45 emitted by optical fiber 15 is reflected by mirror 10, adjacent point 50, toward optical fiber 20 along path 55. When mirror 10 is in a second end position 60 (as shown in phantom) opening 30 is positioned such that light beam 45, emitted by optical fiber 15, passes through mirror 10, via opening 30, toward optical fiber 25 along path 65. Although not shown, light beam 45 can pass through mirror 10 via opening 30 toward optical fiber 25 along path 65.

Additionally, mirror 10 may also be positioned between first end position 40 and second end position 60. This incremental positioning of mirror 10 acts as an attenuator in that a first portion of light beam 45 is reflected by mirror 10 to travel along path 55 while a second portion, which includes all or some of the remainder from the first portion of light beam 45, is transmitted through mirror opening 30 along path 65. The first portion of light beam 45 may be configured to increase or decrease in intensity along path 55 toward second optical fiber 20 as mirror 10 is positioned between first end position 40 and second end position

60. The second portion of light beam 45 may also be configured to increase or decrease in intensity along path 65 toward optical fiber 25 as mirror 10 is positioned between first end position 40 and second end position 60.

Furthermore, switch 5 may also selectively transmit light beam 55 and light beam 65 from optical fiber 20 and optical fiber 25, respectively, to optical fiber 15. As such, mirror 10 may operate to switch or attenuate light beam 55 and light beam 65.

Mirror 10 is actuated in the preferred embodiment by applying a voltage between a first contact pad 70 and a second contact pad 75. This voltage difference is transferred from the first contact pad 70 and the second contact pad 75 to a first electrode (not shown) and a second electrode (not shown), respectively.

Mirror 10 contains the first electrode (not shown). The voltage difference creates an electrostatic force which causes a first end 32 of mirror 10 to deflect from its original position. As shown in Fig. 2, mirror 10 is unactuated at position 40 and is fully actuated at position 60. It should also be noted that mirror 10 can be partially actuated at any point between position



40 and position 60. Alternatively, mirror opening 30 can be repositioned such that in the unactuated state light beam 45 is transmitted to third fixed optical mirror 25 and in the fully actuated state light beam 45 is reflected toward second fixed optical fiber 20.

In either of the above described configurations, when mirror 10 is in the second end position 60, it is electrostatically held in place against a shock stop 80. As such, mirror 10 will not vibrate due to the electrostatic force holding mirror 10 against shock stop 80. In an alternative embodiment (not shown), another shock stop 80 is also configured opposite to the second end position 60 and adjacent to first end position 40. In this configuration, mirror 10 will not vibrate if an electrostatic force is applied.

In end position 40, without applying an electrostatic force to hold mirror 10 fixedly in place, vibrations may occur in mirror 10. Opening 30 may be sized larger than the width of light beam 45 to compensate for these vibrations.

Now referring to Fig. 3, there is shown an nxn switch and variable optical attenuator array 85. Switch array 85 utilizes a mirror 90 and a first series

of fixed optical fibers 95, a second series of fixed optical fibers 100, and a third series of fixed optical fibers 105. Each series of optical fibers 95, 100, 105 has a number of optical fibers represented by numerals from 1 to n. Further, the number of optical fibers in each series 90, 100, 105 is typically the same. Mirror 90 contains openings 110a-110n for allowing light beams 115 to pass, in the manner described below. The number of openings 110 is equal to the number of optical fibers, n, in each series. Generally, each of the optical fibers of first series 95 is associated with one of the mirror openings 110, with one of the optical fibers of second series 100 and with one of the optical fibers of third series 105, as illustrated in Fig. 2. That association will be described herein.

Mirror 90 can be positioned at an angle  $\theta$  to reflect each light beam 115 emitted by the optical fibers of first series 95 toward the optical fibers of the second series 100 along optical path 116, as shown in Fig. 3. By changing the angle  $\theta$  of mirror 90, each light beam 115, or a portion thereof, is allowed to pass through its respective opening of openings 110 and

toward the optical fibers of the third series 105 along optical path 117.

In an alternative embodiment, mirror 90 has nonuniformly configured openings 110. In such a configuration, openings 110 cause some light beams 115 to be reflected into the optical fibers of the second series 100 while other light beams 115 pass through mirror openings 110 toward the optical fibers of the third series 105. Each of the openings 110 may be uniquely positioned in mirror 90 to allow varying degrees of intensity of light to be reflected and/or transmitted to the several optical fibers along the second and third series 100, 105 while the mirror 90 is at a single position.

Mirror 90 is actuated in the preferred embodiment by applying a voltage between first contact pad 120 and second contact pad 125. This voltage difference is transferred from the first contact pad 120 and the second contact pad 125 to a first electrode (not shown) and to a second electrode (not shown), respectively. Mirror 90 contains the first electrode (not shown). The applied voltage difference creates an electrostatic force which causes a first end 128 of mirror 90 to

deflect from its original position opposite its base at  
a second end 130. A shock stop 135 is positioned  
adjacent to the first end 128 end of mirror 90,  
opposite to its base adjacent to point 130, at each  
5 terminal portion of deflection.

Now looking at Figs. 2, 4a-4d, 5a-5b, and 6, a  
method is disclosed for the fabrication of a switch.  
As seen in Fig. 4a, a SOI wafer 140 is provided having  
two Si layers 145a and 145b with a SiO<sub>2</sub> layer 150  
10 therebetween. Alternatively, the switch may be  
configured out of two conducting materials separated by  
an insulating layer therebetween; or two non-conducting  
layers separated by an insulating layer, provided that  
electrodes are deposited onto the non-conducting  
15 materials, e.g., GaAs/SiO<sub>2</sub>/GaAs. In essence, the wafer  
may be fabricated out of two etchable materials  
separated by an etchant stop. Next, top side 155 of  
the wafer 140 is configured with a pattern (not shown)  
and on the bottom side 160 of the wafer 140 is also  
20 configured with a pattern (not shown). These patterns  
guide the etching described herein. An etchant is  
applied to the bottom side 160 to realize an initial  
portion via-hole 165b through Si substrate 145b (see

Fig. 4b). In a preferred embodiment, a wet etchant, such as KOH, is used to realize the initial portion via-hole 165b in the bottom side 160 of Si substrate 145b.

5 Now looking at Figs. 2 and 4c, an etchant is applied to the top side 155 to realize v-grooves 166 and mirror 10. In a preferred embodiment, a wet etchant, such as KOH, is used to realize v-grooves 166 (see Fig. 2) and mirror 10 (see  
10 Fig. 4c) in Si substrate 145a.

Looking at Figs. 5a and 5b, opening 30 is realized in mirror 10 using Deep Reactive Ion Etching (DRIE). In order to begin formation of opening 30, a thin layer of SiO<sub>2</sub> is grown to protect each V-groove 166 (see Fig.  
15 2) and mirror 10 (see Fig. 4c). Any protective film previously applied to wafer 140, such as during its manufacture, is removed using Deep Reactive Ion Etching (DRIE). Such a protective film may include a silicon  
20 forming opening 30 includes applying etchant in two timed steps at portion 170 (see Fig. 5a) with opening 30 being realized at the conclusion of the application.

Now looking at Figs. 4c and 4d, a via-hole 165a is realized to complete a via-hole 165 through wafer 140 (see Fig. 4d). First, the  $\text{SiO}_2$  layer (not shown) is removed from the surface of mirror 10. Second, the  $\text{SiO}_2$  layer 150 is removed from between the openings 165a, 165b formed in each of the Si substrate layers 145a, 145b. For example, in a preferred embodiment a buffered oxide etchant is used to remove the  $\text{SiO}_2$ .

In order to finalize switch 5, looking at Figs. 2 and 4d, wafer 140 is oxidized and electrodes are added as described below. One preparation method includes oxidizing wafer 140 with 100 nm of silicon dioxide. Then, a first surface (not shown) and a second surface (not shown) of wafer 140 are each metalized to form a first electrode (not shown) and second electrode (not shown), respectively. In a preferred embodiment, the surface of mirror 10 is one of the electrodes. The surface of this electrode also provides an enhanced reflecting surface. As such, the metalization deposition provides reflectance for the mirror 10 as well as the conductance for the electrode. An example of a metalization deposition involves first covering a surface with chromium for adhesion and then covering

the chromium surface with gold to create an electrode. First, contact pad 120 and second contact pad 125 are applied to wafer 140 and are electrically connected to the first electrode and the second electrode,

5 respectively. To complete fabrication of switch 5, the mirror structure is diced from the wafer and placed onto an optical component package. The preceding sequence of steps illustrated above may be varied, e.g., top side 155 could be etched prior to etching  
10 bottom side 160, etc.

The silicon wafer 140 is typically composed of a single crystalline structure, referred to as "(100) silicon". The Miller indicies "(100)" describes the crystalline structure of a unit cube of silicon. The  
15 structural configuration of the "100" silicon causes etching to occur at a 45° angle relative to the origin of the unit cube. This is advantageous in that wafer 140 is etched at a known angle, which subsequently allows the precise alignment of optical fibers 15, 20  
20 and 25. Additionally, due to the structural configuration of the silicon wafer, etching permits mirror 10 to be formed with a very flat surface.

Higher yields and lower costs for production of optical switches are possible due to the simplicity of the fabrication process, described above. Standard starting materials, such as 4-inch and 6-inch wafers, 5 can be used for fabrication. Wet etching of wafer 140, described above, is usually a multi-wafer process. Deep Reactive Ion Etching (DRIE) of wafer 140, which is usually a single wafer process, has a low process time. These factors allow high volume production using this 10 fabrication process.

Additionally, the  $\text{SiO}_2$  layer acts as an insulator to reduce the current loss into the silicon wafer. This configuration reduces the power requirements of the unit. 15